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Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centers of the arid and semi-arid state of Rajasthan, India

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A B S T R A C T

Trend analysis of the mean (monsoon season, non-monsoon season and annual) and extreme annual daily rainfall and temperature at the spatial and temporal scales was carried out for all the 33 urban centers of the arid and semi-arid state of Rajasthan, India. Statistical trend analysis techniques, namely the Mann–Kendall test and Sen's slope estimator, were used to examine trends (1971–2005) at the 10% level of significance. Both positive and negative trends were observed in mean and extreme events of rainfall and temperature in the urban centers of Rajasthan State. The magnitude of the significant trend of monsoon rainfall varied from (−) 6.00 mm/hydrologic year at Nagaur to (−) 8.56 mm/hydrologic year at Tonk. However, the magnitude of the significant negative trends of non-monsoon rainfall varied from (−) 0.66 mm/hydrologic year at Dungarpur to (−) 1.27 mm/hydrologic year at Chittorgarh. The magnitude of positive trends of non-monsoon rainfall varied from 0.93 mm/hydrologic year at Churu to 1.70 mm/hydrologic year at Hanumangarh. The magnitude of the significant negative trends of annual rainfall varied from (−) 6.47 mm/year at Nagaur to (−) 10.0 mm/year at Tonk. The minimum, average and maximum temperature showed significant increasing warming trends on an annual and seasonal scale in most of the urban centers in Rajasthan State. The magnitude of statistically significant annual extreme daily rainfall varied from 2.00 mm at Jhalawar to (−) 1.64 mm at Tonk, while the magnitude of statistically significant extreme annual daily minimum and maximum temperature varied from 0.03 °C at Ganganagar to 0.05 °C at Jhalawar, respectively. The spatial variations of the trends in mean (monsoon season, non-monsoon season and annual) and extreme annual daily rainfall and temperature were also determined using the inverse-distance-weighted (IDW) interpolation technique. IDW results are helpful to identify trends and variability in mean and extreme rainfall and temperature in space and time for the study locations where the data is not available and the quality of data is not good. These spatial maps of temperature and rainfall can help local stakeholders and water managers to understand the risks and vulnerabilities related to climate change in terms of mean and extreme events in the region.

1. Introduction

Increasing urbanization, populations and economies are causing adverse impacts on the natural environment. With increases in urbanization, problems related to climate change are becoming worse, since additional pervious areas are becoming impervious, leading to decreases in vegetation cover and increases in temperature. Rapid economic development and population growth in various parts of the world such as India have caused concerns regarding the quantity and quality of natural resources, and in particular water resources. As such, information on the magnitude, duration and frequency of

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extreme events (such as floods and droughts), along with trends in various hydro-meteorological variables, is required for the planning of optimum adaptation strategies for the sustainable use of natural resources such as water (e.g., Kampata et al., 2008; Some'e et al., 2012; Huang et al., 2013). Mall et al. (2006) have studied the potential for sustainable development of surface water and groundwater resources within the constraints imposed by climate change. The authors suggested that little work has been done on hydrological impacts of climate change for Indian regions/basins. Therefore, assessment of climate change is required in India which considers the causative factors of climate change (i.e., anthropogenic factors, global warming in terms of variations in meteorological parameters) at spatial and temporal scales. Further, it is essential in hydrological modeling to assess the adverse impacts of climate change on water resources. Such studies are even more significant for urbanized watersheds/areas to better understand the relationship between climate change and hydrological processes, which will facilitate the sustainable utilization of water resources.

There are different methods that can be used in the assessment of climate change. Various parametric and non-parametric statistical tests have been used in the recent past by many researchers to assess trends in hydro-meteorological time series in India (e.g., Gadgil and Dhorde, 2005; Singh et al., 2008a, 2008b; Basistha et al., 2009; Kumar et al., 2010; Pal and Al-Tabbaa, 2010; Deka et al., 2012; Duhan et al., 2013; Jeganathan and Andimuthu, 2013; Jain et al., 2013), and in other regions of the world (e.g., Zhang et al., 2000; Zhang et al., 2001; Roy and Balling, 2004; Cheung et al., 2008; Motiee and McBean, 2009; Sahoo and Smith, 2009; Zin et al., 2010; Tabari et al., 2011; Nalley et al., 2012; Nemec et al., 2012; Saboohi et al., 2012; Jiang et al., 2013). Detection of past trends, changes, and variability in the time series of hydro-climatic variables is very important in understanding the potential impact of future changes in the region (Sahoo and Smith, 2009). Statistical analysis could be extended to analyze climatic parameters and their relationships with water resources, land use/cover changes, urbanization etc.

It has been seen that the Earth's average temperature has increased by 0.6 °C in the later part of the 20th century; there is also a dramatic shift in temperature change from a minimum of 1.4 °C to a maximum of 5.4 °C as reported by the projections made by various climate prediction models (IPCC, 2001). The IPCC has demonstrated that climate change assessments at sub-national (i.e., state or province) and local scales are needed. The IPCC has also found several gaps in the knowledge that exists in terms of observations and research needs related to climate change and water (IPCC, 2007). These include GCM scale resolutions and downscaling techniques to locale scales to assess the climate change and to quantify the contribution of anthropogenic activity to climate change etc.

It has been found that seasonal and annual air temperatures have been increasing at a rate of 0.57 °C per 100 years (1881 to 1997) in India (Pant and Kumar, 1997). The trends of certain hydro-climatic variables have been studied in Indian urban centers such as Hyderabad, Patna, Ahmedabad, Surat, Bangalore, Mumbai, Nagpur, Pune, Jaipur, Chennai, New Delhi, Kanpur, Lucknow and Kolkata, whose populations are more than 1 million (De and Rao, 2004). Significant increasing trends were found in annual and monsoon rainfall over Chennai, New Delhi, Kolkata and Mumbai. Other climatic parameters were not considered to assess climate change impacts on timing, distribution, pattern, frequency, variability of precipitation and their inter-relationships in urban cities. Arora et al. (2005) explored trends of annual average and seasonal temperatures using the MK test at the country and regional scales in India. It was observed that annual mean temperature, mean maximum temperature and mean minimum temperature have increased at the rates of 0.42, 0.92 and 0.09 °C $(100\ \text{year})^{-1}$, respectively. On a regional basis, stations in Southern and Western India show rising trends of 1.06 and 0.36 °C $(100\ \text{year})^{-1}$, respectively, while stations in the North Indian plains show a falling trend of 0.38 °C $(100\ \text{year})^{-1}$. The seasonal mean temperature has increased by 0.94 °C $(100\ \text{year})^{-1}$ for the post-monsoon season and by 1.1 °C $(100\ \text{year})^{-1}$ for the winter season. This study deals only with trend detection of temperature; in addition, trends in annual extreme daily events of rainfall and temperature have not been studied.

Basistha et al. (2007) assessed the spatial trends of rainfall over Indian subdivisions from 1872 to 2005. Their results show decreasing trends of rainfall over North India excluding Punjab, Haryana, West Rajasthan, and Saurashtra, and increased trends in South India excluding Kerala and Madhya Maharashtra. The study also concluded that the arid portion (i.e., western part) of India has not been investigated in detail. Further, they highlighted that more research is required to assess the spatial patterns of trends of other climatic variables (average, minimum and maximum temperatures, relative humidity, wind speed, evapotranspiration (ET), number of rainy days etc.) and their inter-relationships including trends of annual and seasonal climatic parameters to assess the impacts of climate change. Gowda et al. (2008) studied the region of Davangere district over a period of 32 years using statistical analysis. Climatic parameters (i.e., rainfall, relative humidity, maximum temperature, minimum temperature, sunshine hour and wind speed) were analyzed to assess climate change. The statistical analysis showed that such a small data set may not represent the correct picture of climate change and requires long term data. A significant change in climatic variables was found in and around the Davangere region. Ghosh et al. (2009) observed the varied trend in Indian summer monsoon rainfall, which has not only been affected by global warming, but may also be affected by local changes due to rapid urbanization, industrialization and deforestation. Patra et al. (2012) detected rainfall trends in the twentieth century in India using parametric and non-parametric statistical trend analysis tests. The temporal variation in monthly, seasonal and annual rainfall was studied for the Orissa State using data from 1871 to 2006. The analysis revealed a long term, insignificant, declining trend in annual as well as monsoon rainfall, and an increasing trend in the post-monsoon season. Rainfall during winter and summer seasons showed an increasing trend. The study only assessed rainfall for Orissa State; trends in mean and extreme annual daily events were not explored. Duhan and Pandey (2013) investigated the spatial and temporal variabilities of precipitation in 45 districts of Madhya Pradesh (MP), India on an annual and seasonal basis. The MK test and Sen's slope estimator test were used for trend analysis, and an increase and decrease in the precipitation trend were found on annual and seasonal bases, respectively, in the districts of MP. In this study, little attention was given to urban trends of